Abstract

In many coastal regions, activities of multiple users present a growing strain on the ecological state of the area. The necessity of using integrative system approaches to understand and solve coastal problems has become obvious in the last decades. Integrated management strategies for social-ecological systems (SESs) call for the development of SES indicators that help (i) to identify and link the states and processes of social, economic and ecological subsystems and (ii) to balance different stakeholder objectives over the long-term within natural limits. Here we use a system dynamics modeling approach called group model building (GMB) as a diagnostic participative tool for understanding the determinants of characteristic SES issues in the Dutch Wadden Sea region and exploring salient SES indicators for management. We used GMB in two separate workshops for two distinct cases: sustainable mussel fisheries and tourism development. Follow-up online questionnaires elicited relevant variables for deriving SES indicators. In both modeling cases participants identified and connected the variables that expressed fundamental SES dynamics driving each issue. In the mussel fisheries model the central part of the structure was the interaction between the model variables 'extent of mussel habitat with high natural value', 'mussel cultivation efficiency', and 'market supply'. In the tourism model a key driving force for explaining tourist development was the reciprocal relation between the model variables 'natural value', 'experience value', and 'number of tourists'. Application of GMB revealed SES issue complexity and explicitly identified key linkages and potential SES indicators for policy and management in the Dutch Wadden Sea area. As a tool for stakeholder involvement in integrated coastal management the approach enables the joint building of system understanding and the exchange of individual perspectives. Participants agreed with the jointly created model and highly appreciated the way the structured approach facilitated communication and learning about complex and contested issues.

Keywords: Group Model Building; Indicators; Social-Ecological Systems; Integrated Coastal Management; Wadden Sea

1. Introduction

The necessity of using integrative system approaches to understand and solve environmental problems has become obvious in the last decades. The development of knowledge for Integrated Coastal Management (ICM) requires identification of the components, both natural and human, of the ecosystem, and understanding their relationships to manage them in an integrated context (Turner 2000, De Jonge et al. 2012). The framework of *social-ecological systems* (SESs; Ostrom 2009, McGinnis and Ostrom 2014) highlights the complex feedback loops between humans and nature that can create unsustainable dynamics and undesirable outcomes such as degraded ecosystems and negatively affected ecosystem users (Glaser et al. 2012). The integrative demands of the SES concept call for the development of human-environmental indicator sets that help to identify and link the states and processes of ecological, social and economic subsystems (Jørgensen et al. 2013). But although the importance of suitable information infrastructures for ICM is widely accepted, there is an increasing awareness of the complexities in identifying, monitoring and evaluating relevant interactions (Glaeser et al. 2009).

Modeling is a widely applied instrument for integrating and structuring social and ecological complexity, as well as for facilitating communication and understanding between scientific disciplines and between science and management (Den Exter 2004). Models have historically been used in support of natural resource management and policymaking, often in a quantitative and highly formalized (i.e. computerized) form (Mirchi et al. 2012, Laniak et al. 2013). But although formal models are used in many resource management applications, there is increased recognition that the role and impact of human systems have often been overlooked or at least underrepresented in many models (Schlüter et al. 2014;Voinov and Bousquet 2010). While greatly improved computer capabilities are driving a growing use of the systems approach for complex issues in other research fields, the application to SESs lags behind (Hopkins et al. 2012). A possible reason for this is the difficulty of integrating knowledge on variables and their relationships from both the social and the ecological domains (Schlüter et al. 2014).

Increasing our insight into complex socio-ecological systems helps to understand environmental problems better, but is not sufficient for solving them. We also need to motivate stakeholders to take action. There is increasing demand for participation of stakeholders in ICM not only as sources of information but as active and involved actors in decision-making as well (Stringer et al. 2006, Hanssen et al. 2009). There is evidence

(Korsgaard, Schweiger and Sapienza, 1995; Nutt, 2002) that stakeholders are more likely to implement proposed actions if they participated in a joint process of building understanding of the issue at stake.

Model building is used more and more as a tool to structure discussion and debate about issues, and to create a learning environment that allows assumptions to be tested. Participative and stakeholder based policy designs can be organised around a model in which diverse interests are brought together to build a shared level of understanding and consensus (De Jonge and Giebels 2014; Voinov and Bousquet 2010). In this view, models are not only valued for providing solutions; in addition, they offer a way to understand and learn more about the system being modeled (Vennix 1996, Cockerill et al. 2009).

1.1 Modeling of complex systems

Many approaches to developing models of complex systems have been pursued such as Bayesian networks, couple component-, agent-based or knowledge-based models, and system dynamics. Bayesian networks use probabilistic rather than deterministic relationships to describe the connections among system variables. The approach of coupling component models involves combining models from different disciplines or sectors to come up with an integrated outcome. Agent-based models describe the observed world in terms of factors (agents) that are characterized by certain rules (behaviour) whereas in knowledge-based models knowledge is encoded into a knowledge base and then an inference engine uses logic to infer conclusions. Finally, system dynamics (SD) is concerned with understanding how the behavior of systems changes over time and is gaining in popularity because of its flexibility and structural focus (Kelly et al. 2013). The premise underlying the approach is that the dynamic behavior of complex systems is a consequence of system structure. Building SD models can help to systematically understand the time lags, nonlinearities, accumulation and feedbacks that characterize the relationships among system components (Sterman 1994, Groesser and Schaffernicht 2012). There are two mutually reinforcing sides to the SD modeling process (Kelly et al. 2013). First the process is directed at eliciting the causal assumptions that experts and end users have about the system (known as mental models), and testing the validity of these assumptions. Secondly SD applications engage experts and end users in the modeling process, fostering values of openness, diversity, and self-reflection (i.e. social learning purpose).

SD modeling has been applied in various environmental studies (Stave 2002, Den Exter 2004, Van den Belt 2004) and more specifically in sustainable development (Kelly 1998, Antunes et al. 2006, Hjorth and Bagheri 2006), and water resources problems (Winz et al. 2009, Mirchi et al. 2012) amongst others.

SD modeling can help to identify critical information about structures and feedback loops underlying SES issues within a particular system. The formulation of concrete cause–effect-chains or webs of relations between variables can provide a foundation for the development of relevant SES indicators in decision making (Kandziora et al. 2013). By facilitating the exploration of salient social-ecological feedbacks an SD model can provide fundamental understanding of leverage points for sustainable solutions (Kelly 1998, Mirchi et al. 2012). Empirical case studies in applying the SD approach in SES issues in ICM are limited. Exceptions are the use of SD to identify sets of indicators (Sanò and Medina 2012) and for artisanal fisheries analysis (Camanho et al. 2011).

1.2 Group model building as a tool for understanding SES issues

In this study we want to explore the SD methodology as a tool for ICM and indicator development. Specifically, we apply a form of participatory modeling (Voinov and Bousquet 2010) , namely group model building (GMB; Vennix 1999) as a conceptualization and learning method that helps to understand SES issues and work towards the development of indicators for ICM in the Dutch Wadden Sea region. This coastal region represents a typical social-ecological system, i.e. a system that is a continuously changing and coevolving through interactions between users, institutions, and natural components (Holling 2001, Liu et al. 2007, Ostrom 2009, Schlüter et al. 2014).

As is the case for many coastal areas around the world, management issues in the Wadden Sea region can be considered as “wicked”, “unstructured” or “messy” (Kabat et al. 2012). Such issues are not of a technical nature and do not have a definite formulation nor a well-described set of potential solutions. Their definition depends on the perspective taken by the observer, i.e. on how the problem is looked upon by each of the stakeholders involved (Head & Alford 2013, Jentoft and Chuenpagdee 2009, Sanò et al. 2014). Conditions for “messiness” are present in the Wadden Sea region as its governance is characterized by the involvement of many institutions, overlapping jurisdictions, and multiple users with different backgrounds, bringing their own vocabularies, knowledge, and ways of operating in the governance arena (Hanssen et al. 2009, Giebels et al. 2013, Puente-Rodríguez et al. 2014). Because of their wicked nature, coastal problems can only be managed on the basis of a joint understanding of the situation and of stakeholder goals.

We apply GMB in two case studies in the Dutch Wadden Sea region to document how stakeholders perceive the development of two sectoral issues, i.e. sustainable mussel fisheries and tourism. The cases - sustainable mussel fisheries and tourism - present two major issues in current policy and management. Both cases concern multiple stakeholders with different interests and involve issues with important system knowledge uncertainties (Vugteveen et al. 2014). The underlying assumption of this study is that SD modeling has the potential to integrate different points of view and elicit understanding on SES indicators by facilitating analytic deliberation and learning amongst stakeholders in SES issues. In our approach we focus on i) identifying variables and their interrelationships, in this case explaining mussel fisheries and tourism dynamics, and ii) identifying key variables that have relevance for SES indicator development.

In the following section we introduce our study area and cases and describe their SES characteristics. Next we explain the method of group model building and how we applied it. In the fourth section we present the GMB models and key variables for SES indicators. Finally we discuss our findings and identify benefits and limitations of GMB use in ICM.

2. The cases: developments in sustainable mussel fisheries and tourism in the Dutch Wadden Sea region

We considered two cases in the Dutch Wadden Sea region, both within the context of the Wadden Sea Long-Term Ecosystem Research (WaLTER) project (WaLTER project team 2010). The Dutch Wadden Sea area is recognized as one of the world's most valuable coastal areas, having attained a World Heritage status in 2009 (Kabat et al. 2012), and protective status under EU Natura 2000 and national nature legislation. Though nature protection is the primary management goal, multiple socio-economic activities take place in the area such as fishing, shipping, extraction of natural gas and salt, agriculture and tourism. The natural processes and these socio-economic activities form a complex interplay in which the major challenge for management is how to match the economic activities in and nearby the Wadden Sea with the unique natural values of the area.

Knowledge about past, present and future developments and management of the natural environment, cultural heritage and socio-economy of the Wadden Sea region is not only important to the region itself but of great interest to other coastal lowlands and tidal zones in the world (Kabat et al. 2012). The WaLTER project (2011-2014) has been initiated to develop a plan for adaptive monitoring providing a basis for a better understanding and integrated management of environmental issues relevant to the Dutch Wadden Sea Region. Initiated by a number of research institutes and organisations that carry out long-term measurements in the economic and ecological domain, WaLTER aims to integrate and improve existing monitoring programmes, fill possible gaps in the current monitoring network, and make existing and new data more readily accessible (WaLTER project team 2010). The main product of the project is an online portal that makes monitoring data and information available and accessible for all stakeholders.

2.1. Sustainable mussel fisheries

Mussel cultivation in the Netherlands is based on sea bed cultivation and takes place on mussel cultivation plots in the Western Wadden Sea and the Easter Scheldt. In the Wadden Sea these plots are predominantly in the sublittoral areas, i.e. areas that are permanently under water. For cultivating mussels juvenile mussel resource material is necessary, so-called mussel seed or spat. This is traditionally being fished from natural seed beds in the sublittoral part of the Western Wadden Sea. The collection of mussel seed normally takes place twice a year. In autumn fishing occurs on newly formed and instable seed beds that have a higher chance of disappearing in winter. In the following spring seed fishing takes place on the remaining beds in more stable areas. The amount of spat fall each year varies greatly due to a complex relation between a set of factors that is not yet completely understood (Folmer et al. 2014).

Fishermen traditionally use bottom trawling techniques, which, as nature organizations have brought forward repeatedly over the years, have possible adverse effects for the environment. In February 2008, a convenant on sustainable mussel fisheries practices was agreed upon between the mussel industry, government and environmental organizations laying out a trajectory until 2020 for the conversion of traditional seed fishing practices to use alternative methods (Convenant "Transition Mussel Sector and Nature Restoration Wadden Sea", hereafter called the Transition Process; LNV 2008). The alternative method of choice for the production of raw material for cultivation is the use of Mussel Seed Capture Installations (MSCIs). The Transition Process takes place in gradual steps whereby the mussel sector should remain profitable and the effectiveness of MSCI application is repeatedly evaluated (LEI 2014). The closing of areas for seed fishing is part of the Transition Process and takes place primarily in areas where mussel beds have the greatest chance of survival. Once areas are closed, they remain closed so mussel beds may develop undisturbed. Monitoring is implemented to evaluate whether the non-targeted seed beds indeed develop into habitats with rich biogenic structures.

2.2. Tourism

Tourism is a well-developed and highy competitive economic activity within the Dutch Wadden region. The Wadden Sea landscape forms a major attraction for tourists due to its unique nature, its quietness and open spaces, and its cultural heritage on both the islands and along the coast. Most tourism and recreational activities in the area are focused on the experience of nature and landscape involving water sports, cycling, walking, beach recreation and mudflat walking. The Wadden Sea area is a very popular tourist destination; tourists spend over ten million nights in the region each year and the sector is producing revenues of around one billion euros annually (Stuurgroep Waddenprovincies 2013). The extent of development and the nature of tourism activities vary considerably across the Wadden Sea area. Three main areas can be distinguished: the Wadden islands, the Wadden Sea and the mainland coast. Most of the revenues in the sector are generated on the islands (Sijtsma et al. 2012).

Recreational use in the natural areas may pose pressures on the environment. The growth of tourist numbers over the years has increased concerns amongst nature organisations about adverse effects on natural values (Raad van de Wadden, 2008). Policies on recreational use are laid down in various policy convenants including among others agreements for recreational boating. The UNESCO World Heritage status requires policy strategies maintaining sustainable tourism ”that respects both local people and the traveller, cultural heritage and the environment” (PROWAD 2013, page 5). The Dutch Wadden Fund (2014) has indicated that the coherence between different tourist facilities and activities should be strenghtened, and that the UNESCO World Heritage status should be used as a connecting element in presenting the many possibilities of tourism and promoting the Wadden experience as a whole. This goal has now been laid down in the World Heritage Tourism Strategy (PROWAD 2013) enacted at the trilateral – i.e. Dutch, German, Danish - intergovernmental conference in Tønder (Denmark) in early 2014.

Focal points in the regional policy for sustainable recreation and tourism are the development of transport infrastructure and spatial planning with an aim to developing tourist hubs and creating better access to cultural-historic places of importance. Emphasis is on developing the physical conditions for recreation and tourism. The Heritage status will also be used in education, promotion and marketing to position the exceptional values of the area as a whole and at a trilateral level.

3. Group model building workshops

Group model building (GMB) refers to a bundle of techniques used to construct system dynamics models working directly with client groups on key strategic decisions (Vennix 1996). The approach involves a group of stakeholders in one or more sessions in building a conceptual and /or formal model. An experienced facilitator helps the group to build the model, remaining neutral with regard to the content.

The problem that is modelled can be reasonably well defined, but more commonly takes the form of an ill-defined or messy problem (Vennix 1999, Andersen et al. 2007). GMB is used in business applications as well as public settings, including natural resource management (Stave 2010). What is similar across all these applications is the assumption that stakeholders should be an intrinsic part of a systems analytical approach to solving management issues, and that time needs to be spent developing shared understandings of the system to be managed. This should involve the groups and individuals who know the system best, who are embedded within it and who hold a stake in what happens to it (Stringer et al. 2006). The goals of GMB are therefore not limited to producing a particular outcome, i.e. a conceptual or formal model, but also include process aims such as enhancing mutual understanding, defining terms and notions, sharing experiences and perspectives to foster consensus (Vennix 1996, Voinov and Bousquet 2010).

SD modeling includes qualitative and quantitative modeling methods. Qualitative modeling, for instance using influence diagrams or *causal loop diagrams (CLD)*, is directed at improving conceptual system understanding. Quantitative modeling, visualized in the form of *stock-and-flow diagrams (SFD)*, is used to investigate the effects of different intervention strategies, using data and mathematical relations to simulate the system's behavior (Wolstenholme 1999, Coyle 2000). A hybrid form that combines CLD and SFD can be referred to as a *system structure diagram* (SDD; Groesser and Schaffernicht 2012).

In this study we use qualitative modeling and produce a system structure diagram for the case of mussel fisheries and a causal loop diagram for the tourism case. These types of model are equivalent in the sense that they highlight feedback loops. A system structure diagram is different from a causal loop diagram in that it shows aging chains in the form of a series of stocks linked by flows. For the mussel fisheries case (see Figure 1 below) an aging chain seemed a logical choice because the development from larvae to full-grown mussels is a central part of the problem and is most clearly depicted as an aging chain.

Both types of diagrams however assist systems thinking by summarizing complex problems, and identifying the relationships and feedback loops that help to explain behavior, generate insights and finally provide the basis for a quantified model where appropriate. SD diagrams use words to describe model variables and arrows to illustrate causal connections. These connections can be positive or negative. A positive connection is used when two variables change in the same direction (*ceteris paribus*). A negative causal arrow is used when two variables change in opposite directions (*ceteris paribus*). Combinations of positive and negative causal relationships may form feedback loops that are either balancing (negative) or reinforcing (positive). Analysis of system dynamics models focuses mainly on these feedback loops, as they are seen as drivers of behavior over time (Richardson 2013).

Two workshop sessions were organized in January 2014, one on mussel fisheries and one on tourism. Through our earlier work on information needs of Wadden stakeholders (Vugteveen et al. 2014) we were familiar with the stakeholder and actor playing field in Wadden Sea management and research issues. Care was taken in identifying and selecting relevant stakeholders in both case studies. For any participative project the selection process is essential as whoever is present at the meeting will shape the process and the outcome (Ulrich 2003, Hanssen et al. 2009). Participants of the mussel fisheries workshop included 15 representatives from fisheries, NGOs, research institutes, consultancies and marine managers. Participants of the tourism workshop included 18 representatives from research institutes, consultancies, regional government (i.e. provinces), NGOs and tourist organizations. Both sessions comprised multiple disciplines and stakeholder groups with different interests, in an effort to ensure a comprehensive representation of the system. Participants received financial compensation for their work.

Our methodological approach involved three steps. The first two steps were performed in the workshops, the final step through an online follow-up survey:

1) identification of key issues and important variables;
2) system conceptualization – identifying and specifying linkages between variables in an explicit and logical way;
3) identification of key variables with high information value that in turn inform the identification of SES indicators.

A team of two facilitators guided the workshops. A process facilitator steered discussions and helped to elicit the knowledge, experience, and expertise of the group. The second facilitator supported the first and took the role of modeler to build the model and summarize modeling steps to the participants. For modeling the systems dynamics tools Vensim@DSS was used (Ventana Systems 2010). The Vensim model was projected on a screen visible to all participants. Furthermore two (mussel fisheries) or three (tourism) observers were present to take notes on group discussions. These notes were used in reporting.

After an explanation the goal of the session and a round of introductions of the participants we started with a preliminary "concept model", a small conceptual model that introduces the concepts, iconography, and points of view of the system dynamics approach (Richardson 2013). We then asked participants to answer the following question: *what variables play a role in sustainable mussel fisheries / tourism in the Wadden Sea region?* We explained that variables could be causes, influences, effects or elements of the issue. Variables were gathered by using Nominal Group Technique (Delbecq et al. 1975). In this technique participants are invited to write down relevant variables individually, on a piece of paper. These are then gathered by the facilitator in a round-robin fashion, i.e. an arrangement of choosing all elements in a group equally, and listed next to the Vensim model projected on the screen. Next the model was constructed real-time in a facilitated deliberation on relationships between variables. Variables and relations were only included in the model if participants agreed.

After the workshop an online follow-up survey was sent to the participants. The survey was directed at verifying the variables and relations in the model. Participants were also asked whether the relations in the model needed adaptations or corrections. The survey was developed using Qualtrics software (www.qualtrics.com).

Based on the feedback received from all participants some adaptations were made to the model. Importantly the consensus model of the session was not altered based on single comments. Comments only led to adaptations of the model when they involved technical or logical inconsistencies or a consistent use of terminology, and were mentioned by more than one participant. For both cases the end report sent out to participants featured the final model, a list of comments gathered via the online survey, clarification of adaptations carried through and (in the appendix) the model developed in the session[1].

4. Findings

This section describes the models for sustainable mussel fisheries and tourism . The models are developed on the basis of the sessions and online survey; they are not complete and do not pretend to be. A premise of GMB is that the final model is a joint product of the group's learning experience, and that a model is always an abstraction of reality. The knowledge and expertise of the participants in the session drive the selection of the variables and relations to be included in a model. The models contain those elements that participants with different ecological and socio-economic viewpoints agree to be the most important. Specified variables are included in the model after consent by all participants. In SD and GMB the quality of a resulting model is judged in relation to its purpose. We made clear to participants that the models aim to represent participants' opinions. In order to test the validity of the models as descriptions of the SES processes in the Dutch Wadden Sea region, the models would need to be formalized so that structure and behavior can be compared against available data sets. Among others, this would require an estimation of parameter values and equations. This was however beyond the scope of the WaLTER project.

4.1 Sustainable mussel fisheries

Figure 1 shows the system structure diagram on sustainable mussel fisheries. The lower left segment of the model describes the growth dynamics of mussels from a mussel fisheries production perspective. The model distinguishes between different destinations of mussel seed; in part the seed forms wild sublittoral and litoral mussel beds, partly it is bottom trawled in the sublitoral and partly captured by MSCIs. Next to reproduction and growth there are losses of mussels at different growth stages. Mortality of mussel seed is included in the model as a primary loss factor. The causal factors of mussel seed mortality are included in the mid left segment of the model and involve biological factors such as predation by crab and starfish, physical factors such as wash out and mussel seed density. The dynamics of spat fall in the Wadden Sea are primarily determined by the survival of the larvae and not by their total number. Larvae numbers are not a limiting factor under the current circumstances in the

[1] The reports can be found online (in Dutch): i) Vugteveen et al 2014.Group Model Building over mosselvisserij in de Waddenzee. WaLTER project 38 pages. ii) Vugteveen et al 2014.Group Model Building over toerisme in het Waddengebied. WaLTER project 37 pages. See www.walterwaddenmonitor.org.

Wadden Sea; spat fall dynamics in this model rather refers to the proces that explains how the supply of larvea is divided across compartments (MSCI, littoral seed). There is a huge variation in spatfall between years and locations because of several factors. As emphasised in particular by the fishermen the model needs to take stochastics into account. This is indicated in the model by the variable ‘dynamics out of human control’. The general agreement amongst participants is that from a fisheries perspective spat fall on MSCIs is more certain than bottom spat fall. In addition, spat fall in the sublittoral seems more regular than in the littoral areas.

The lower right model segment deals with the economic cost-benefit considerations of fisheries, linked to the physical mussel production part of the model. The supply of mussels and the auction price determine revenues and profits in the sector. The Dutch fishermen compete with international producers on the international market. When prices for mussels are high processing industries might switch to importing mussels or replace mussels by other products. Production costs are an important variable and linked to maintaining a certain production capacity. Labor costs are an important element of total production costs. Employment and labor costs are strongly related to an increase of MSCI capacity. Compared to traditional bottom trawling MSCI activities require more workers, for instance for transportation of material or maintenance. Within the context of the Transition Process it is relevant to separately specify production costs and investments within the model, so as to be able to evaluate traditional mussel culture against innovations (‘fishing fleet’ against ‘MSCI capacity’). The upper left segment expresses that the extent of habitats with a high natural value is determined by the presence of natural littoral and sublitoral mussel beds, as well as cultivation plots. A very important factor for understanding the extent of mussel habitats and their development is the ‘stability of the mussel beds’. Bed stability is a policy criterion for allowing autumn seed fisheries - as these are only allowed on instable beds - as well as a main determinant for the natural value of beds (i.e. older beds have high nature value).

The right upper segment of the model covers regulations and production space. Regulations determine the ‘production space’ for the sector in terms of seed fisheries and half grown mussels. ‘Cultivation efficiency’ is a central variable and influenced by several factors including the ‘quality of the culture plots’,‘cultivation- and maintenance activities’ carried out by mussel farmers and by existing ‘regulations’ on moving mussel spat between plots (i.e. ‘North-South transports’). Natural factors (such as growth climate, predation, available food) show a certain amount of natural variation and also vary per location, thus determining the quality of cultivation plots. The search for suitable locations and amount of space needed for cultivation plots is a recurring discussion within the Convenant and amongst other users like the shrimp fisheries sector.

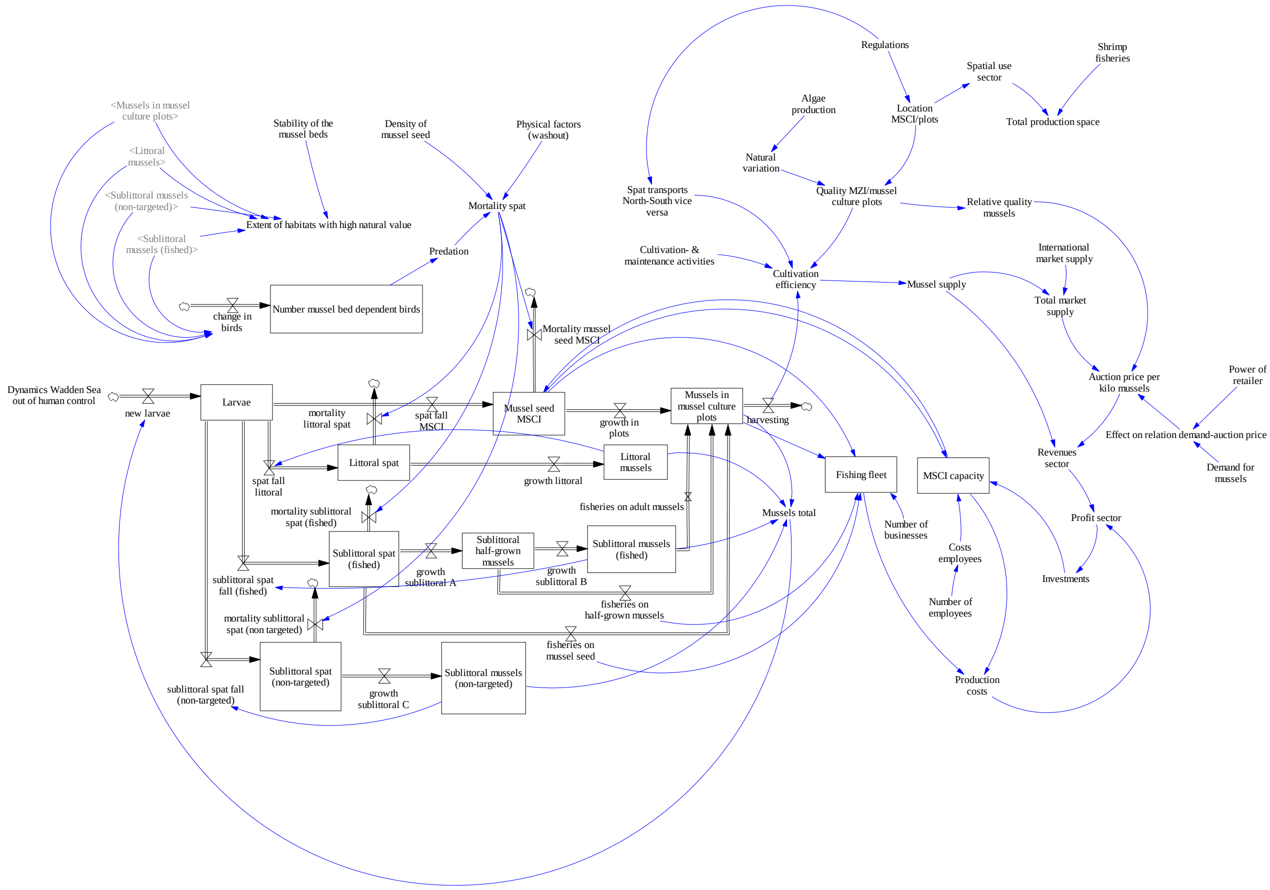

Figure 1. Final system structure diagram on sustainable mussel fisheries in the Dutch Wadden Sea region

4.2 Tourism

The lower segment of the tourism model in Figure 2 describes the basic interplay of supply and demand in recreative facilities. The ‘number of tourists’ is a central variable in the model. On the basis of a particular number of available ‘recreational facilities’ in terms of ‘capacity’ and ‘quality’, a particular number of tourists can be accomodated, generating revenues. The economic significance of recreation and tourism in the area is expresssed as that part of revenues that remains in the area and contributes to local welfare. In the middle right hand segment ‘experience value’ is the central variable. Experience values are values that relate to personal experiences and appreciation of the environment, such as, in the case of the Wadden, quietness, openness of the landscape, and attractiveness of the beach. Nature experience is a specific experience value that is linked to natural values present in the environment. The options available for experiencing nature, like bird and seal watching, are very important for tourism and recreation in the region. Tourism and recreational activities may impact nature values, either negatively (disturbance) or positively (indirectly through societal support for nature protection).

The monitoring of birds and seals is currently receiving attention in the Convenant on recreational boating, an agreement between nature organizations, recreational organizations and the government. 'Sustainability' and 'innovation' are positively linked to the 'experience value of a tourist'. Sustainable development in tourism means that its long-term development does not harm important natural values. Examples of innovation linked to experience value are the use of local products and offering energy-neutral "eco" accommodations.The middle left hand segment covers use values. Use values relate to useability for and coherence of the environment to visitors. The variabel 'use value' in this segment is about aspects related to functional quality of the environment and facilities offered. 'Marketing and promotion' influence expectations and perceptions and indirectly are inputs to experience- and use values. Finally the topmost part of the model contains a segment on policies and innovation. The model distinguishes between nature and innovation policies. 'Nature policies' are positively linked to 'natural values' and are restrictive for tourism and recreation in the area. 'Innovation policies' are positively linked to 'adapation capacity', the potential of the sector to develop or adapt within the boundaries of nature- and economic policies.

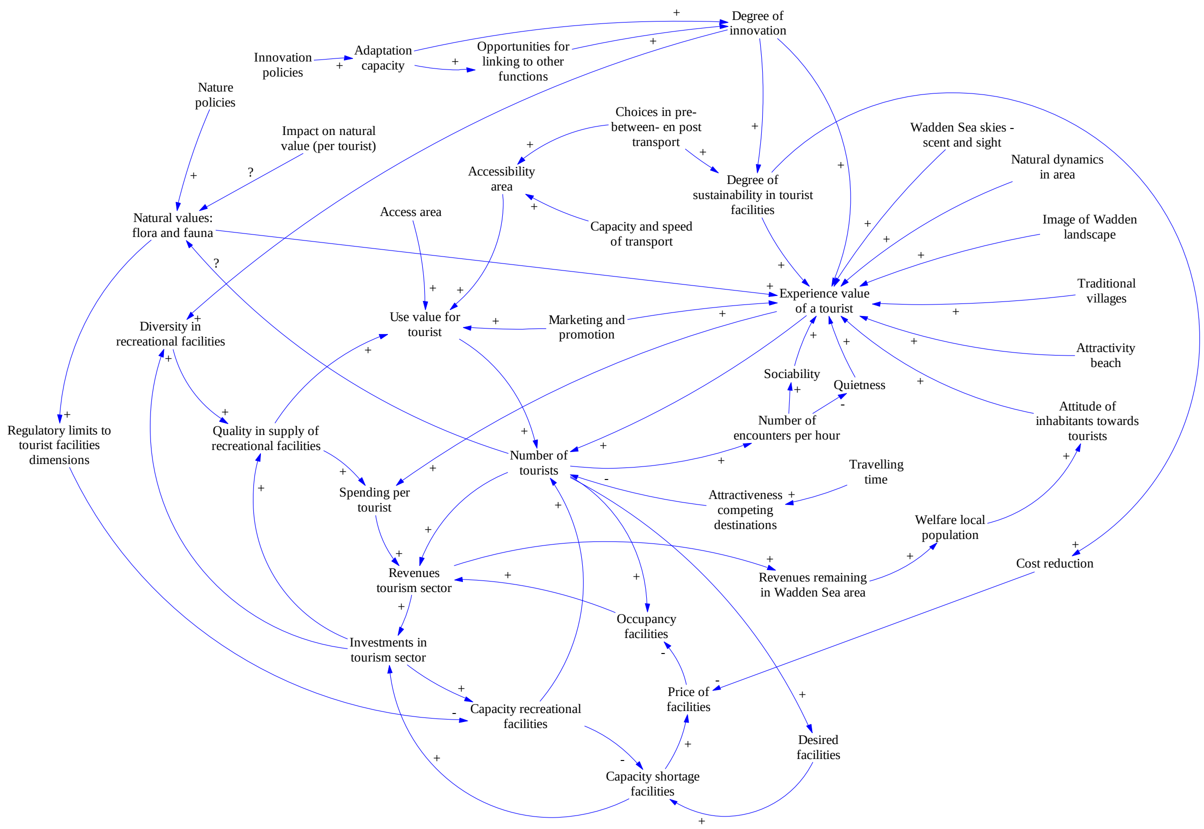

Figure 2. Final causal loop diagram on tourism in the Dutch Wadden Sea region

4.3 Key variables – towards SES indicators

We performed an online survey to elicit key variables in both models: those variables that in the eyes of participants provide valuable information on the issue modeled. The identification of these variables is a first step in the development of relevant SES indicators.

Here we only consider substantive arguments to identify indicators. Other common criteria used to decide on indicators such as ease of use, scope, quantification or sensitivity are not considered at this stage. Participants mentioned 20 key variables for mussel fisheries and 18 for tourism. Table 1 presents those key variables that were selected by most participants. They are key in the sense that participants would welcome better understanding and data with regard to these factors. See Table 2 for an explanatory description of these variables.

Table 1. Key variables selected by participants. The second column presents the number of loops that variables are part of. The third column presents the number of participants that selected the variables.

Sustainable mussel fisheries		**Loops**	**# Part.**	**Tourism**		**Loops**	**# Part.**
1.	Cultivation efficiency	2	4	1.	Experience value	21	11
2.	Extent of habitats	0	4	2.	Number of tourists	37	9
3.	Total market supply	1	4	3.	Revenues tourism sector	32	7
4.	MSCI capacity	22	3	4.	Revenues remaining in the Wadden Sea area	9	6
5.	Stability of mussel seed beds	0	3	5.	Natural values: flora and fauna	12	5
6.	Sublittoral spat (non-targeted)	31	3				

Note: Figure 1 shows several outflows which are not influenced by the level of the relevant stock (i.e. the stock is not connected to the outflow by an information link). In a formal model this would mean that the stock level does not pose a limit to the outflow, meaning that the value of the stock potentially falls below zero. If a stock represents a physical quantity such as the number of mussels, this is unrealistic and would indicate a flaw in the model. In order to calculate the number of loops through each variable, we have added information links of each stock to its corresponding outflow.

As mentioned in the above, system dynamicists see feedback loops as the most important part of model structure as loops drive behavior. On the basis of a qualitative diagram, however, it is difficult to make inferences about loop dominance and their impact on behavior. What is possible is to determine which variables are part of loops and in this sense are important elements of model structure, an approach similar to identifying central nodes in cognitive maps (Eden 2004). An interesting question is to what extent variables that according to participants have the most information value, are also enclosed in feedback loops. Table 1 shows that for the tourism case, variables that according to participants are most informative are also enclosed in many loops (the minimum number of loops in which variables are enclosed is 0, maximum 37, median 4). For the case on mussel fisheries, the minimum number of loops in which variables are enclosed is 0, maximum 64, median 17. Here participants choose two variables which are part of many loops (MSCI capacity and non-targeted sublittoral spat), but four others are not. Two of these are exogenous variables that represent conditions that impact the mussel ecology and economy: extent of habitat and stability of mussel seed beds. According to participants, model variables do not have a major impact on either of these conditions. Finally there are two economic factors that are important to some stakeholders but are enclosed in only one or two loops: cultivation efficiency and total market supply (see Table 2). We may conclude that in these cases, participants tend to choose informative variables which are part of feedback loops or represent important conditions central to their stake in the issue.

Table 2. Key variables for SES indicators

	Potential SES indicator	Description
	Sustainable mussel fisheries	
1.	Cultivation efficiency	Cultivation efficiency is a basic statistic for mussel cultivation, expressed as the amount of consumable size mussels produced from a certain amount of mussel seed. Although efficiency has improved over the years still only a relatively small part of used production seed grows into consumable size mussels. Circumstances for cultivation are controlable to a certain extent and loss is a fact of nature. Improvement of cultivation efficiency may lead to higher acceptance of fishery activities by NGO's (lower costs and less seed fishing). Good measurement of cultivation efficiency enables the identification of reasons for slow growth and mortality.
2.	Extent of habitats	Annual inventories of mussel stocks are performed for policy reasons, including the evaluation of management measures and effect studies for N2000 legislation. The surface area of present mussel beds is measured yearly. Except for economic value, determination of surface areas is also important for establishing natural values. Natural values express the ecological importance of mussel beds in the Wadden Sea and are defined within conservation objectives.
3.	Market supply	Market supply determines auction prices and eventually consumer prices. When the prices for Dutch mussels become too high, consumers will switch sooner to import mussels or replacement products. It is important to monitor the total supply of mussels and their alternatives from within the Netherlands and abroad. Essential information includes volume, prices, quality, and information on market players and markets.
4.	MSCI capacity	MSCI capacity is a variable in the economic production part of the model and involves the extent (number of installations) and production capacity of MSCI. It is necessary to monitor MSCI capacity to determine whether mussel seed capture is economically viable. MSCI capacity can be expressed in square meters of MSCI (occupied surface, where no ships are allowed) and in terms of seed production. The latter is important for estimating the production value of MSCI's in total seed production. An important question is how large production volume can be over over the years. The quality of MSCI locations also needs to be measured (variable 'quality of MSCI/plots'). Important for production are food supply, flow velocities and sensitity to storms on locations. Depth is important for the suitability of MSCI locations and of (indirect) influence to MSCI capacity as nets or ropes need to remain clear of the sea bed.
5.	Stability of mussel seed beds	The stability of mussel beds is a decisive factor for fishability (steering 'fish plans') as well as for natural value. Insight is necessary in the size and volume of instable beds. Important stability factors are hydrodynamics (wave action), predation (starfish, crabs), durability and structure of the beds (adhesion force). Especially hydrodynamic stress is an important limiting factor for the presence of mussel beds.
6.	Sublittoral spat (non-targeted)	Numbers on biomass densities in space and time are important basic statistics for the fishery production chain. The amount of spat fall and surface areas of existing beds are important determinants for the total natural value of an area. At the moment it is still unclear what drives the spat fall and long-term survival of mussels. Measurement of the surfaces of non-targeted beds is also important to gain more insight into the survival chances of young mussel beds.
	Tourism	
1.	Experience value	In landscape research experience value has been defined as the (experience of) the total attractiveness of the landscape. The 'pleasance' of the landscape is an important aspect; a landscape with a high experience value 'pleases the senses'.

		In the total experience of an observer the visual aspect, or ‘scenic beauty’, often plays a dominant role although other sensoric experiences like hearing and smell also influence total experience. Participants mentioned the scent and wide views in relation to the Wadden Sea skies. A high experience value is an important motivation for tourists to visit the Wadden Sea region. Better quantification of experience value is necessary to gain more insight into the degree to which different parts of the Wadden Sea region are appreciated by visitors.
2.	Number of tourists	The number of tourists/visitors presents a basic statistic for tourism monitoring and is important for understanding the dynamics of the sector. To measure the societal value of an area it is important to measure how intensive an area is being “used”. Also data on visitor numbers may be used to determine whether capacity of facilities is sufficient. The monitoring of tourist numbers is also important for gaining insight into how the World Heritage status influences tourism in the region. Participants in the session did indicate that the model should account for different types of tourists and spatial differences.
3.	Revenues tourism sector	Revenues are a basic economic statistic for determining the importance of the tourism sector for the whole economy. At the moment limited information is accessible on specific revenue data for the whole region.
4.	Revenues remaining in the Wadden Sea area	Numbers on the share of revenues remaining in the region is important to determine the contribution of tourism to the local economy. Numbers per subarea are required to weigh local economic interests (against natural areas for example). The numbers may also be used to account for investments within the sector (as a contribution to local welfare). From a policy perspective it is important to gain more insight into how revenues, i.e. profits, in the region flow back to the region. A participant specifically mentioned that local population, especially along the coast, do not profit sufficiently of “their” Wadden Sea region.
5.	Natural values: flora and fauna	Knowledge on natural values is important to develop sound spatial policies, i.e. where human use is to be allowed or prevented. From a tourism development perspective the understanding and analysis of natural values in relation to experience values is essential. Natural values are an important motive for visits to the area. There is still limited insight into how tourism and natural values mutually influence each other. For example, the amount of effect of recreational boating on birds and seals remains unclear.

5. Discussion and conclusion

In this study we demonstrated the use of a GMB approach to elicit the complexity of two SES issues and explicitly identify key variables and linkages as a first step in the development of relevant SES indicators for policy and management in the Dutch Wadden Sea region.
In the mussel fisheries model (Figure 1) the key structure involves a linkage between the variables ‘extent of mussel habitat with high natural value’ - expressing the area of available mussel beds -, ‘mussel cultivation efficiency’ - i.e. how many and how efficient mussels may be produced - and ‘market supply’, i.e. how many mussels may be sold and consumed. In the case of fisheries practices cultivation efficiency and MSCI capacity were found important variables to be measured. When the yield of cultivation plots and efficiency of operations improve less pressure on the environment is expected as mussel seed resources are used more efficiently. Location is a key factor for cultivation results. Data on MSCI locations and MSCI

capacity are necessary to determine whether there is enough volume in MSCI seed production for a profitable business operation. In the context of evaluating the succes of the Transition Process it is also found important to follow developments in market supplies in relation to competitiveness of the sector within the (inter)national market. Witin current mandatory monitoring efforts the extent of mussel habitat is an important parameter. As an regulatory indicator, i.e. for determining fishable areas, the parameter is found suitable but as an ecological indicator a more comprehensive indicator is found necessary. The mussel fisheries model indicates the stability of mussel beds is a major determinant in the (perennial) development of mussel habitat. Adding depth to extent of habitat as an indicator requires better understanding of the factors determining stability according workshop participants. At the moment it is still not completely understood what drives the spat fall and long-term survival of mussel beds (Folmer et al. 2014).

The tourism case revealed that experience of Wadden nature and landscape is one of the most important motives driving recreational and tourism activities in the Wadden Sea region. In the tourism model (Figure 2) participants expressed this key driving force for explaining tourist development as a linkage between the variables ‘natural value’, ‘experience value’, and ‘number of tourists’. The number of tourists drives the ‘revenues’ to be gained, the latter being a basic indicator for economic productivity. Participants explicated in the model that next to total revenues generated it is also important to understand what the share of revenues is that remains in the region. In current monitoring programmes basic statistics on tourists numbers and sectoral revenue figures are represented. However, these data do not cover the Wadden region as a whole and are comprehensive enough. A recent policy document of the Wadden provinces shares this conclusion by mentioning the need to monitor small scale accomodations since these play an important role in improving the quality of tourist facilities and the promotion of Wadden-specific hosting (Stuurgroep Waddenprovincies 2013). Finally, the tourism model puts forward that experience value is an essential variable to understanding of the development of tourism. Structural data on experience values is limited however. In the context of monitoring experience values a recent approach called Hotspotmonitor is worth mentioning. Sijtsma et al. (2012) developed a web-based tool for the (inter)national Wadden Sea region offering a spatially explicit way to measure attractiveness of the landscape, places and specific individual experiences.

5.1 Benefits and limitations of group model building

As a methodological approach GMB offers several benefits when applied to complex multi-dimensional ICM issues (Heemskerk et al. 2003, Winz et al. 2009, Mirchi et al. 2012, Langsdale et al. 2013). Noted benefits include the flexibility and transparency of the method, the capacity to integrate qualitative and quantitative information, the ability to integrate a wide range of input parameters in a meaningful way (reflecting their inherent interactions and feedbacks), and an explicit recognition of multiple forms of uncertainty (Winz et al. 2009). Importantly, the GMB approach provides a tool for stakeholder involvement in ICM and making management relevant to local concerns. Participating in the modeling process helps stakeholders to develop a shared representation of the scope and complexity of management problems and enables the exchange of knowledge and individual perspectives.

In our workshops participants highly appreciated the way the structured group model building process helped communication and learning processes. Participants explicitly stated that the approach allowed them to develop a more comprehensive understanding of the system. They thereby not only referred to the structured process as such but also to the guidance and support of the professional facilitators, a role that has demonstrated to be very helpful, if not essential in decision-making processes (Hanssen et al. 2009; De Jonge and Giebels 2014). In the context of effective management the social learning aspects of the approach are very important as they enhance mutal trust and provide support for (future) decisions (Hanssen et al. 2009, Stave 2010, Mirchi et al. 2012).

A limitation of the way GMB was used in these two cases is the assumption that ‘the answer is in the room’ (Geurts et al. 2006). The input to the model consists of participants’ understanding of the issue at stake. There was no opportunity to check statements and facts real-time against other data sources that could have revealed potential biases in participants’ assumptions. The qualitative model built in these cases, unlike a formal model, cannot be simulated over time which means that its validity can only be assessed to a limited extent. Although the sessions did not result in a formal model, the elicitation of issues that were important to stakeholders and the development of conceptual models contributed to process of learning and consensus-building. A group modeling process may help in resolving disparate system concepts and inconsistent terminology between social and natural scientists and in fostering the integration of science and values (Niemi and McDonald 2004). As such the approach provides a mechanism for integrating scientific knowledge with tacit knowledge.

In a more general sense a significant benefit of system dynamic modeling stems from its ability to facilitate conceptualization of multidisciplinary models by providing a number of qualitative tools to complement quantitative simulations (Wolstenholme 1999, Coyle 2000). Mirchi et al. (2012) note that especially the field of water resource management is accustomed to a tradition of developing highly quantified models but useful qualitative modeling tools like GMB tend to be overlooked.

In terms of systems learning the process of model development may point to areas where relationships are poorly understood and where additional data need to be gathered. A claimed advantage of using a system dynamics approach over other methods for developing indicators is that it provides a transparent and rigorous formalized approach for problem structuring (Wolfslehner and Vacik 2011). A GMB approach assists in providing a conceptual framework, i.e. model, for what needs to be indicated and helps to set an appropriate context for indicators. In comparison to traditional approaches for deriving indicators (Bossel 1999, Bowen and Riley 2003) the use of GMB may enable identification of more meaningful indicators since the approach does not focus on identifying individual indicators but considers the larger picture of the issue, i.e. how indicators interrelate and may be combined.

Furthermore, a key factor influencing the acceptance and success of models is their practical usefulness, i.e. addressing the right problem at the right scale and scope (Winz et al. 2009). In GMB this is what makes a model valid, i.e. whether it is appropriate for its purpose and whether model users have confidence in it (Sterman 1994, 2002). In this study the method helped experts and users to make their views explicit and identify key variables, providing a basis for SES indicators that are seen as important by the stakeholders involved in the system, instead of being solely theory-based (Jørgensen et al. 2013).

5.2 GMB application for better SES management

The outcomes of our study suggest that GMB is a potentially useful tool especially where i) recognition and understanding of system complexity is required; ii) stakeholder knowledge needs to be integrated; and iii) communication and learning amongst stakeholders is desired (Den Exter and Specht 2003). In using GMB we were able to produce meaningful and focused representations of the underlying system structures that determine mussel fisheries and tourism. The models that were produced delivered relevant and new system understanding by formulating critical cause-effect relationships and salient feedback loops within the Wadden Sea regional system. Furthermore GMB application allowed the identification of explicit key variables with high information value for stakeholders in the Wadden area providing a basis for the development of relevant SES indicators. As such we think GMB models can be a valuable tool in the design of adaptive monitoring programs and in developing experimental setups for addressing research questions (Vugteveen et al. accepted).

Further research may be directed at quantifying our currently qualitative model and determine whether the selected key variables for SES indicators are also part of the most dominant quantitative loops. Structural dominance methods (Kampmann and Oliva 2009) or analyses of loop impact (Hayward and Boswell 2014) may be applied. Secondly the challenge is to deal with the uncertainty inherent to social-ecological systems. This relates to system uncertainty originating from both knowledge gaps and stochastics. In our sustainable mussel fisheries model (Figure 1) such uncertainty was depicted in the variable 'Dynamics Wadden Sea out of human control'. Recently developed tools and workbenches to determine robust options in situations of deep uncertainty may be used (e.g. Kwakkel and Pruyt 2013a, 2013b). Applying these tools to a running simulation model of our models could test the robustness of the model and policy options that could be derived from the model.

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